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ROBOTICS: MILITARY APPLICATIONS FOR SPECIAL OPERATIONS FORCES

by

George M. Pierce II, Major, USAF

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Advisor: Lieutenant Colonel Randy Soboul, USA

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Preface

This paper is an overview of robotics, particularly the current state and future for Tactical Mobile Robots (TMR), from a special operations force (SOF) perspective. Ground robotics technology is somewhat of a well kept secret, but for it to become viable in the military, the word needs to get out. This paper is an attempt to begin spreading the word. Currently robotics and unmanned vehicle development parallels the same path aircraft development faced 80 years ago; however, today's technology is moving at a significantly faster pace. Before robotic platforms are able to revolutionize the military the same way the airplane did, we must begin to figure out the tactics to exploit their potential and employ them correctly. Hopefully, this paper will generate enough enthusiasm to help get the ball rolling to make it happen. There are numerous people I wish to thank who helped make this effort. Beginning with LTC John Blitch, thanks for introducing me to robotics, providing the hours of education, and helping me track down points of contact. Next, I would like to thank all those who participated in my interviews; I know they were painful, but let me assure you, your information was indispensable. I would especially like to thank LTC Randy Soboul. No one could have asked for a better faculty research advisor and particularly for giving me a hard time "every time" I saw or spoke to you. You kept it fun. You gave me the Army perceptive, invaluable guidance, and kept me on track, Hooah! Also thanks to Major Courtney Holmberg for his scientific perspective and editorial polishing. As always, I owe a great deal of thanks to my wife, Joanne. Yet again, her patience and support help make it possible. Thanks Joanne!

Abstract

New technology may be able to help answer the cries to reduce casualties resulting from friendly fire and collateral damage, as well as assist the military in performing urban operations. Unmanned vehicles, whether air, land or sea, are one means to get our airmen, soldiers, marines, and sailors out of harm's way and are most likely a key driver to an upcoming revolution in military affairs (RMA) for all services. The major objective of the paper is to bring attention to of Tactical Mobile Robots (TMR) and hopefully encourage follow-on studies and to cultivate an enthusiasm to employ them correctly to help get our troops out of harms way and win battles. This study focuses primarily on the use of TMRs in the special operations environment. The paper discusses the current and immediate TMR capabilities; key logistics concerns regarding maintenance, supply, and transportation; and two possible scenarios, one in an unconstrained battlefield and the other in an urban environment. The data collected was primarily via conducting interviews and witnessing experiments and they highlight a few barriers, which must be addressed if unmanned platforms are to keep pace with congressional orders.

Part 1

Introduction

Since Karl Capek's play, *Rossum's Universal Robots*, when most people think of robots, they envision mammoth automatons made of metal with almost human-like features. They see these creatures lumbering out of spaceships which have just landed on earth, like in the movie *The Day the Earth Stood Still.* Science fiction writers and Hollywood unfortunately have not only given society a grave misperception of robots, but also delayed their incorporation into our day-to-day existence. Today, there is a significant delusion of what robots can really do and what they should look like. Also, some would argue that the scientific community has spent too much time trying to replicate human-like features. However, it wasn't until the scientific breakthroughs in computers and micro-miniature technology during the last 15 years that ground robots could even become possible.

New technology may be able to help answer the cries to reduce casualties resulting from friendly fire and collateral damage, as well as assist the military in performing urban operations. Unmanned vehicles, whether air, land or sea, are one means to get our airmen, soldiers, marines, and sailors out of harm's way and are most likely a key driver to an upcoming revolution in military affairs (RMA) for all services. The major objective of the paper is to bring attention to the rapidly moving field of Tactical Mobile Robots (TMR) and hopefully encourage follow-on studies to cultivate an enthusiasm to employ them correctly. This study focuses primarily on the

use TMRs in the special operations environment. The data was collected primarily via conducting interviews and witnessing on-going experiments. These experiments highlight a few barriers which must be addressed if unmanned platforms are to keep pace with congressional orders.

The paper begins with a brief history on the field of robotics and the five imperatives that define operational use for these platforms. Next, it discusses the current and impending TMR and sensor capabilities. The paper then addresses potential missions for robotic platforms by discussing tactics and employment considerations and looking at the issues concerning robotics and loss of life. This section concludes with two possible operational scenarios. The first is a combat undertaking using robotic platforms in an unconstrained battlefield to determine the feasibility of an airstrip for a SOF mission. The second scenario portrays how TMRs could be used in an urban environment to help remedy a hostage situation. Next, the paper addresses key logistics concerns regarding maintenance, supply, and transportation. The last section provides an overview of the major issues discovered during this research and offers some conclusions and recommendations for bringing robotics technology to the warfighter.

Part 2

Background

Historical Background

The military has attempted to insert robotic technology into aerial platforms since World War I, where attempts primarily focused on remotely controlling dirigibles. The first real breakthrough was in World War II when a modified B-17 successfully performed unmanned flights.[1] Unmanned Aerial Vehicles (UAVs) have had much more success than their ground counterparts because they do not have to contend with obstacles, and the means by which aerial vehicles maneuver is easier to control.[2] Aerial flight maneuvers do not have to contend with surface-to-surface frictions (wheels steering on a ground surfaces). Instead, they move surfaces to redirect airflow. The lack of obstacles (for the most part) and similar flight characteristics as aircraft have also allowed Unmanned Underwater Vehicles (UUVs) to progress faster than robotic ground vehicles. Additionally, UUVs became essential for exploration, rescue, and recovery operations in the vast ocean depths. Humans cannot remain for extended periods below 200 feet or even dive at all to much greater depths. So for operations to take place in deep seas another means had to be developed. Naval submarine operations also help justify the requirement for UUV rescue operations. The Navy had deemed UUVs as mission essential and needed to meet various requirements. On the other hand, requirements for robotic ground vehicles were often seen as a luxury or unjustifiable.[3] In addition to UUVs with submarine or

aircraft like features for water operations, there is also an almost science fiction looking crab called the Autonomous Legged Underwater Vehicle (ALUV) as shown in Figure 1.

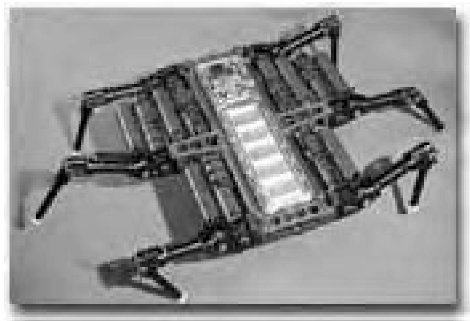

Figure 1. ALUV

The ALUVs will be deployed into the surf zone from UUVs where they will then maneuver to a preprogrammed search area (shallow water and beach) to detect mines and barricades. They can also double as reconnaissance scouts.[4]

Tactical Mobile Robot development did not truly begin until the early 1990s. Until then, the military's primary focus for ground robotics was in developing Unmanned Ground Vehicles (UGVs).[5] For purposes of this paper it is necessary to differentiate between UGVs and TMRs. UGVs are vehicles that have been equipped with robotic technology and are transport oriented or perform tasks normally in their line-of-duty. For example, remote controlled dozers moving dirt or tanks accomplishing de-mining operations are categorized as UGVs.[6] Robotic platforms that are task or work oriented, did not previously exist as a vehicle, and are normally small enough to accommodate no more than a two-person carry will be considered TMRs.[7]

Five Imperatives

LTC John Blitch of the Defense Advance Research Projects Association (DARPA) has established five imperatives that TMRs must meet before they are considered technologically capable for SOF operations. These imperatives will help ensure SOF mission success by

addressing the key environmental and operational requirements such as overcoming potential obstacles, communicating significant distances, operating in hostile areas, anti-handling protection (prevent unwanted handling or tampering), functioning autonomously (maneuver without commands from an operator), or not needing humans to rescue them when something goes wrong.[8] Under certain mission scenarios, one or more of the imperatives could be relaxed; but as a general rule, a TMR should be able to meet them all.[9]

First Imperative

A TMR must have the ability to reorient itself upright or to operate upside-down.[10] Due to the TMR's smaller size and the requirements to operate in extremely rough terrain (including negotiating stairs) and carry a variety of payloads, they are in jeopardy of "turn turtle" (flipping over) and becoming non-operational. Since most SOF missions would be using TMRs to perform dangerous tasks and keep the tactical team members out of harm's way, it would not make sense to rely on putting team members at risk in order to recover or reposition an overturned TMR. Therefore, TMRs must be designed to right themselves or operate upside-down. Operating upside-down requires either a dual set of antennas and sensors or the ability to reposition them so the TMR can continue to function without losing communication links or sensor availability. If the TMR is designed to upright itself, consideration must be taken to protect both antennas and sensors so they continue to function after the turn over and uprighting process. Also, both design concepts must consider what the TMR will do if it loses its balance and ends up on either side. Today most TMRs either have a workable solution or one on the immediate horizon.[11]

Second Imperative

A TMR must have the on-board ability to reposition itself or raise an antenna to reestablish lost communication links.[12] Like the first imperative, this one is also essential in keeping team members out of harm's way. If the TMR loses the communication data link with its operator and does not have a means to reestablish the link, the mission is over. There must be enough on-board intelligence processing capability to recognize when the data link has been lost and then take action to reestablish the link. If the TMR knew it lost the signal, current technology could direct it to trace its path back to its original destination provided the reason for the loss of communications is not due to its current location. For example, it the TMR has fallen off a steep ridge or small cliff, the signal may be blocked and the TMR may also prevented from retracing its path due to the ridge or cliff. This challenge has not yet been mastered because of the amount of processing required to determine if the signal has been lost.[13]

Currently, when the CL-327 a UAV that Air Force Special Operations Command (AFSOC) is testing loses its data link, it executes a pre-defined maneuver. This rotates the UAV through 360 degrees to try and reestablish communications with the ground operators while at the same time flying towards a predefined reversionary point established during prelaunch initialization.[14] Terrain constraints would also have to be addressed in order for TMRs to successfully execute this approach. Presently, for missions where this imperative is absolutely indispensable, the only real solution may be to have TMRs operate via UAV data links relayed to the ground operators or have backup airborne operators in the area during the mission.[15]

Third Imperative

TMRs must have anti-handling mechanisms.[16] Since TMRs operate away from their controller they must have some form of self-protection. There are various situations which will

call for the TMR to protect itself from a curious child or animal, an agitated non-combatant, vengeful terrorists, or group enemy soldiers. Currently it is not possible to train TMRs on how to properly identify and respond to these threats; so, they must have a trustworthy triggering system to alert the operator. Once alerted, the operator can identify the threat and tell the TMR the proper response. To prevent handling, TMRs currently have the ability to generate several nonlethal options: electrically shock, shoot pepper spray, run away, transmit audio warnings, or even initiate self-destruction.[17] The current challenge is for the TMR to immediately and autonomously recognize a potential threat, and then alert the operator with enough data so he can quickly assess the situation and promptly provide proper instructions. The scenario might be that something has spotted the TMR and begins moving towards it. First, the TMR must identify if aggressor is a human or animal. If a human, what type of person is it? Is it a small adult or child? Does the profile indicate they are carrying a weapon? Will this entity compromise the mission? What defense level is appropriate? These questions just begin to highlight the complexity of this imperative. However, LTC Blitch believes the TMR community already has at least a 50 percent solution in hand. Solving the self-protection imperative will also give the TMR deception and distraction functions.[18]

Fourth Imperative

A TMR must 1) have locator means, 2) have position estimation systems, and 3) the means to convey its location to the operator.[19] If the TMR's mission is to locate someone in an urban area but it does not have the ability to tell its operator where it is, it has no mission value. Because TMRs operate indoors as well as outdoors in a myriad of environments, the solution is more than just having an on-board Global Positioning System (GPS) or Inertial Navigation System INS. The resulting solution was a combination of four or five systems, depending upon

accuracy requirement, fused together through a common filter. This type of configuration compensates for GPS signal loss, INS drift, odometer errors, vibrations, bounces, jolts, and skids, thus ensuring there are no single point failures.[20]

Fifth Imperative

TMRs must be able to negotiate stairs.[21] One of the major missions for TMRs is to operatein urban environments. Every multi-story building has stairs and TMRs must have the ability to move freely throughout their surroundings. Climbing stairs, as shown in Figure 2, is a simple function for humans, but one which requires significant ingenuity from the TMR community to solve.[22]

Figure 2. IS Robotics' (ISR) Urban Robot (Note use of flippers)

Depending upon the mission, environment, and hostile threats, it may not be essential for all five of these imperatives to be resolved in order to field a usable system. Also, TMR developers may discover they need to establish additional imperatives once the systems get in the hands of the intended users. As with any SOF system, flexibility will be the key.

Current Robotic Capabilities

Numerous robotic systems and sensors available. Many were developed for commercial uses and are ideal for commercial off-the-self (COTS) acquisitions. Universities, National Aeronautical Space Administration (NASA), and private industry have also developed various systems ranging from anatomically functioning legs to a TMR like system that operates on Mars. This section will focus only on a few of the systems the SOF community is currently studying.

UAVs

At this time, AFSOC is primarily focusing their attention on CL-327 as shown in Figure 3. The CL-327 is a rotary-winged, vertical takeoff and landing (VTOL) UAV which can carry a variety of sensor packages. It has 220lbs cargo capacity and 6.24 hr flight endurance.[23] See Appendix A for additional pictures and specifications.

Figure 3 CL-327 Preparing for Launch

TMRs

There are several contractors and universities developing various families of TMRs. To avoid the perception of government bias, pre-selection, evaluation, or competition, the three TMR families listed below were chosen based upon my familiarity with them.

Lemming. The Foster-Miller Inc. TMR Lemming family began as amphibious robotic platforms as shown in Figure 4. They have functioned in depths up to 60 feet and surveyed areas over six miles long.[24] They have evolved into numerous other platforms to include the Lightweight Unexploded Ordnance Reconnaissance (LUXOR) and its unexploded ordnance-handling partner Tactically Adaptable Lemming Ordnance Negotiator (TALON). They can be controlled either by preprograms or operator commands via a wire or fiber optic tether, radio frequency (RF) signals or ultra wide (UW) acoustic modems.[25] See Appendix B for more pictures and specifications.

Figure 4 Foster-Miller Lemming

RATLER^tm^. Sandia National Laboratories' Intelligent Systems and Robotic Center (ISRC) originally developed the Robotic All-Terrain Lunar Exploration Rover (RATLER^{tm}) as a prototype vehicle for lunar exploration missions.[26] The RATLER^{tm} comes in a range of sizes from eight inches up to three feet long, is lightweight, can be equipped with tracks or wheels, and demonstrated the ability to perform such tasks as surveillance, perimeter control, rescue, and chemical detection. The perimeter detection and control is performed with at least three RATLER^{tm} derivatives.[27] The United States Special Operation Command's (USSOCOM) is procuring Sally, the latest addition to the RATLER^{tm} family see Figure 5.[28]

Figure 5 ISRC's Sally

Urbie. IS Robotics' (ISR) Urban Robot, commonly referred to as Urbie, was specifically developed for military operations in urban terrain.[29] It's rugged construction, man-portable size, ability to maneuver freely in both indoor and outdoor environments, and on-board data-processing capabilities make it ideal for aiding soldiers in overt and covert operations.[30] Urbie is routinely thrown over fences and out windows to demonstrate its durability as shown in Figure 6.

The platform is invertible, as well as equipped with tracked "flippers" that allow the robot to self-right, climb hills or stairs as shown earlier in Figure 2, assumes an upright posture suitable for navigating narrow twisting passages. It is also designed to operate using the principals of supervised autonomy (needs limited input or direction from its operator).[31]

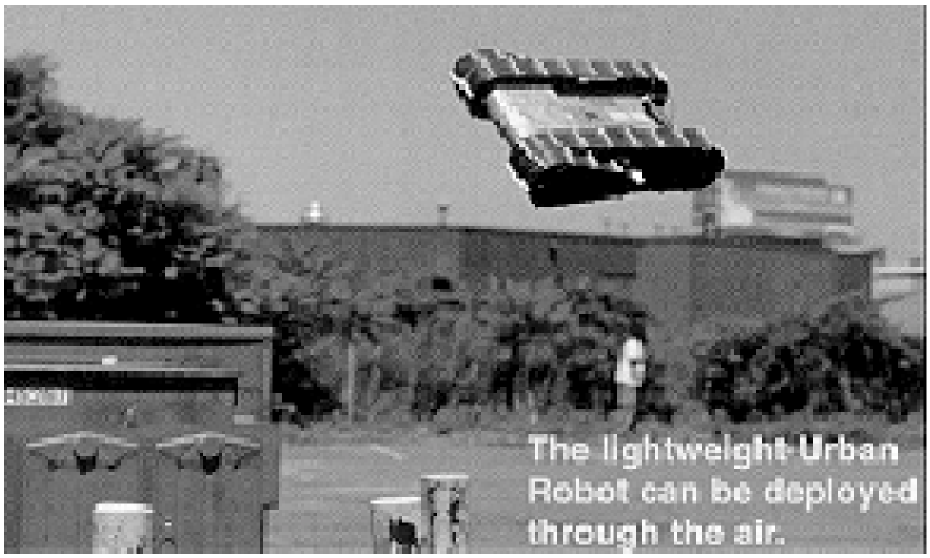

Figure 6 Urbie Demonstrates Its Ruggedness

Sensors

The list of sensors these and other TMRs, UAVs, and UUVs have been equipped with is almost endless and only restricted by one's imagination. Optical sensors such as video cameras at this time are the most common. They include still digital, television (teleoptical), omni-directional, infrared (IR) and night-vision cameras and are usually mounted several per platform in order to provide the operator multiple views.[32] Others sensors which have been successfully operated from TMRs include sonar, metal detectors, tactile, chemical, biological, radiation, explosive, lasers, radiometers, pressure, depth, GPS, INS, radar, angle-of-attack, mapping,

motion detection, and thermometers. Communication links cover the entire gambit from simple radios to broadband data burst systems.

Immediate Future Capabilities

Users' requirements will soon drive future capabilities. As users become more familiar with the potential for robotic platforms and the assortment of available sensors, the requirements may become continuous. Consequently the capabilities will become endless.

UAVs

Besides the CL-327, the AFSOC community is also interested in UAVs that could be launched from their C-130 aircraft while airborne.[33] The concept includes having the ability to launch UAVs to provide pre-mission reconnaissance, to simultaneously insert UAVs and special tactical teams, to directly link data to the aircraft, and the ability to control multiple UAVs from the aircraft. In addition, if TMRs become part of AFSOC tactical teams; they will have the ability to data link UAVs, TMRs, and aircraft with the option to control robotic platforms from either the team's location or the aircraft.[34]

UGVs

New Concepts. Massachusetts Institute of Technology's (MIT) research in developing robotic legs that functioning like a human leg has already demonstrated the technology is attainable and executable. This type of technology has several possibilities to include man assist units that give man greater ability to lift and transport items and more maneuverable robotic units. For example, a legged platform is more adaptable to rough terrain than one with wheels or tracks and may even have potential in prosthesis applications.[35]

New Platforms. The Robotic Combat Support System (RCSS) is a robotic soldier assistant. The RCSS includes a mini-bucket loader, mini-forklift, multi-task attachments, and hydraulic tool power cell. It also has the ability to clear anti-personal land mines.[36] For missions which require more than one TMR, one possibility is the ISRC's four-wheel drive all-terrain vehicle (ATV) Surveillance And Reconnaissance Ground Equipment Robot (SARGE) shown in Figure 7, which can carry a considerable payload. SARGE is also equipped with video cameras, a microprocessor control system, a line of site radio link, and ISRC's Scanner Range Imager System.[37]

Figure 7 ISRC's SARGE

Batteries. Better energy sources and further advances in micro-circuitry are on the mediate horizon for TMRs. Besides trying to improve upon the traditional type batteries, Sandia National Laboratory is exploring fuel cells. These are electrochemical devices that convert a fuel's energy directly into electrical energy, which is an endless (never need recharging) source of energy.[38]

Mini TMRs. IS Robotics and the University of California at Berkeley are collaborating to take advantage of industry's continuous demand for smaller circuitry and are developing a mesoscopic size TMR they call "gecko." Besides being lizard size, it will also have the ability to climb upside-down and scale nearly any vertical surface.[39] Vanderbilt University's version is a 2-inch daddy longlegs with payloads that include video cameras, acoustics sensors and infrared detectors.[40]

Sensors

Sensors, like the components on their TMR hosts, continue to get smaller and more capable. As technology continues to improve upon and go beyond the five human senses, sensors will soon have few boundaries. Bandwidth, or the amount of information that can be passed over a given communication link in a given time, is quickly becoming the biggest constraint. Frequently, more information is available than communication data links are able to transfer.[41]

The AFSOC community is currently developing an Operation Requirements Document (ORD) for an Advanced Remote Ground-Based Sensor (ARGUS).[42] Their immediate need is for an industrial strength, man-portable, ground-based, remotely monitored, surveillance system with the capability to detect, locate, and identify targets in denied areas. The purpose is to fill existing ISR collection gaps to support Intelligence Preparation of the Battlespace (IPB). AFSOC wants the system to have the ability to identify travel routes, force composition, high and low activity areas, aircraft and helicopters presence, and activities at dispersed airfields, and underground facilities.[43] AFSOC identified the requirement to employ ARGUS from any type aircraft or UAV, but did not mention TMRs. The sensor package must quickly detect, locate, identify and track targets; and then either handoff to other ISR collection assets or to a shooter for attack.[44] The ORD does an excellent job of documenting requirements and justifying

continued sensor development, but it misses the opportunity to incorporate ARGUS into a TMR, or at least TMR deliverable. The next big challenge is to develop lightweight, wearable, and user-friendly operator-robot-sensor interfaces, which do not hinder in anyway the special tactical teams ability to accomplish their missions.[45] They are under development, and like TMRs need documented requirements to become a fiscal reality.

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[43] Air Force Operational Requirements Document (ORD) DRAFT, *Advanced Remote Ground Unattended Sensor (ARGUS)*, AC2ISRC 001-99, 24 November 1999.

[44] Ibid.; Morrow.

[45] Blitch; Morrow.

Part 3

Potential Missions

> *Moral strength and intellectual faculty of men are decisive in war, and when applied properly war can be waged with certain success. Only when the enemy cannot overcome these means is there recourse for armed force, which is to be applied so that victory is gained: in the shortest possible time; at least possible cost in lives and effort; with infliction on the enemy of the fewest possible casualties.*
>
> —Sun Tzu

The American public and media have placed new found meaning on this portion of Sun Tzu's philosophy. For now, engaging the enemy and acquiring victory must be done with the fewest casualties possible, especially those resulting from collateral damage or friendly fire.[1] Sun Tzu's doctrine also emphasizes the importance of tactical reconnaissance, observation, and measures designed to ensure security while in camp and on the march.[2] Even today, probing and testing the enemy is still an essential preliminary element of combat operations. However, technology is now on the brink of reducing the need to put human lives at risk as scouts to gather this type of vital information; or performing other dangerous tasks, for example, de-mining operations, detecting chemical or biological agents, and disarming ordnances. This section discusses some of the potential missions for robots by addressing a few possible tactics, raising some employment considerations, and illustrating how robotics serve a force multiplier by keeping our soldiers out of harm's way. Additionally, this section will highlight what robots can bring to the fight in terms of firepower, and then apply those assets to some viable scenarios.

Tactics

In any operation, IPB is a vital ongoing element that every leader must undertake to be successful. To effectively anticipate battlefield events, the commander must clearly understand the current situation.[3] A through IPB provides a systematic and continuous process to reduce uncertainties by addressing these five functions: battlefield area evaluation, terrain analysis, weather analysis, threat evaluation, and threat integration.[4] Robotic technology can play a major role or at least assist in each of these areas.[5] Terrain and threat data can be optically collected either by UAVs or TMRs and provide real-time updates. The UAVs supply the aerial perspective and, depending on the level of secrecy and continuous update, there already exists a cornucopia of platform and sensor combinations to choose from to meet the commander's mission requirements.[6] Whether it is continuous close-in IR images of specific area or a panorama perspective of a large camp or surrounding terrain, UAVs have already proven in Bosnia they can fulfill the mission.[7]

For those situations where additional detail or a ground perspective is required, TMRs can be equipped with existing sensors to meet the need. The ability to watch and listen to the enemy gives a commander the ability to refine the situational template.[8] Additionally, knowing the enemy's doctrine and the ability to identify key actions or threats, addresses threat integration and gives the commander the opportunity to develop counter tactics to halt, disrupt, or prevent the enemy of succeeding.[9] Robotic technology can also assist in using weather or the cover of darkness to the commander's advantage.[10] Both aerial and ground platforms can monitor enemy electronic emissions, conditions, and use sensors such as IR and night-vision cameras to provide sight to the commander the human eye cannot see. Additionally, robotic platforms and their sensors can function as sentries, providing early warning to the operators and key personnel of

potential hazards. For example, robotic platforms can monitor the movement of personnel or vehicles, incoming biological or chemical agents, perimeter breaches, and enemy presence.

Employment Considerations

The first hurdle that must be overcome before any TMRs are employed in the field, is our current military culture.[11] There are numerous cultural barriers that still plague TMRs and even a few for the UAVs. These must be overcome before TMRs are accepted as vital military element.[12] Many still view TMRs as an unproven technology with unknown or little benefit. One major fear is increasing manpower to maintain this new technology that appears to be a potentially huge headache with little capability increase.[13] Even worse is the fear of having manpower reduced because these platforms are perceived as being able to do the work of people, thus justifying the need for fewer people to meet the mission.[14] LTC Blitch believes by the time TMRs are fielded, the technology will have developed the reliability and maintainability requirements such that the "care and feeding" will be minimal. He also stresses the TMR's augmentation role in tactical teams is as a force multiplier and a means to reduce risk…not reduce manpower. The key to resolving these cultural fears is to get the "word out" by demonstrating TMR capabilities.[15]

A problem that plagues both UAV and TMR platforms is who should fund their development? Downsizing and constrained budgets have kept robotics from achieving high-priority acquisition status.[16] The mentality appears to be, "let someone else pay to prove its worth, then we'll jump on the bandwagon to reap the benefits." Until TMRs demonstrate the same success stories as the UAVs and UUVs, this type of thinking will retard real progress. Even though UAVs had great success over the last few years, their capabilities are still not

widely known and excluding reconnaissance, their potential growth into other areas is still limited.[17]

Besides cultural hurdles there are still technological issues that must be resolved. At a minimum, the five TMR imperatives must be quantitatively met before TMR platforms can be employed in the field.[18] The dilemma in premature employment could spell disaster for TMRs and create obstacles that will take an inordinate amount of time to overcome. On the other hand, the sooner this technology gets in the hands of its target audience, the sooner the real benefits will come to fruition…to include getting soldiers and airmen out of harm's way.[19]

Loss of Life

Out of Harm's Way

Placing robotics on the modern battlefield, more pointedly in the hands of our soldiers, airmen, and sailors, will not always prevent lose of lives. However, it will go a long way to help reduce a significant amount of inherent risk. Using robotics via UAVs to collect information from a safe standoff zone is one way our military services have already benefited. Another is just now happening with TMRs in Bosnia.[20] In response to an urgent request from the Army, two prototype Foster-Miller TMRs (shown in Figure 8) were assembled and are currently assisting the 766th Explosive Ordnance Detachment (EOD) to locate, identify, and disarm unexploded bomb ordnance.[21] One TMR uses laser technology and four mini-cameras to locate and identify the ordnance. Then, a larger version TMR equipped with six cameras, an articulating arm, and a claw like hand is used to move the ordnance to a three-sided enclosure where it is safely disarmed.[22] With the help of TMRs, a single detachment was able to set a record disarming eleven unexploded ordnance devices in one day.[23] Officially these TMRs are

undergoing a field test however according to the team leader Sgt. Platt, "This is real-life…There's nothing more real than this."[24] Similar uses might include sending in TMRs to assess damage, and even possibly make repairs, during nuclear catastrophes like Chernobyl. TMRS could measure radiation or use chemical and biological sensors to determine if a building or an area is safe for humans. Additionally, they could infiltrate a highly secure area to collect audio sounds, map obstacles, locate individuals, and monitor movements.

Figure 8. 766 EOD Training in Bosnia

Nonlethal Weapons

Besides keeping our military members out of harm's way, robotic technology also has the capability to gain control of a situation using non-lethal weapons.[25]The use of nonlethal weapons has become an option popular with the American media and several liberal human rights groups. However, military commanders are extremely nervous about this option because our men and women, by the nature of our mission, are trained to destroy their enemy.[26] Our troops are trained

and then briefed on the appropriate "use of force" for each mission.[27] Frequently, peacekeeping missions do not require lethal force, but have the potential to become extremely volatile. These situations could cost our troops their own lives because they may spend an additional second trying to decide whether or not to use a lethal weapon or if they incorrectly choose to use a nonlethal weapon.[28] Robotic technology, specifically TMRs, could very well be one answer. TMRs equipped with nonlethal weapons and controlled by a trained tactical team operating from a safe standoff position could gain control of the situation without lethal weapons, or at least without putting troops in harm's way if a nonlethal weapon was not the right choice.[29] Teleoperated TMRs have the ability to shoot and discharge adhesives, which prevent the target from escaping and nets, which tightly encase the target and prevent them from using their legs, arms, and hands. TMRs can discharge chemical agents like, pepper sprays, and tear gas, which incapacitates or renders the target harmless. Also, they can fire various nonlethal projectiles such as rubber bullets, rubber balls, or bolas. If a human can shoot a weapon via a handheld device, then a TMR can be equipped to do the same, to include lethal weaponry.[30]

Lethal Weapons

The ability to fire lethal armaments from TMRs is not constrained by technologically, but by current "unwritten" policy and doctrine concerning "autonomous releases."[31] One of the biggest concerns, especially for TMRs operating autonomously, is accidental firings resulting in friendly fire casualties, civilian losses, or collateral damage due to technical difficulties, loss of control, or misidentification of targets.[32] The only technological limitations for mounting lethal weapons on TMRs are the size and weight of the weapon and the means of discharge. One major advantage to using TMRs to exploit the firepower capabilities of lethal weapons is the TMRs can be maneuvered into highly dangerous areas and, if necessary, sacrificed to ensure precise

delivery. Autonomous aerial delivery platforms like cruise missiles and numerous other fire-and-forget type munitions were used successfully in Desert Storm and Bosnia, and several variations of combat UAVs are currently under consideration for similar use.[33] UAVs, unlike TMRs, maneuver to their target obstacle free and do not have the potential to come in contact with humans. Additionally, unintentional interference by humans, terrain, or ground vehicles are obstacles TMRs must contend with, which aerial delivery systems do not.[34] Future technological safeguards are needed to increase the confidence factor in TMR delivery systems.

Potential Firepower

Platform size, cargo capacity, and stability during firing are limitations any delivery system, including TMRs, must contend with when determining munitions delivery ability. As discussed earlier, besides these factors, lack of operational imagination is probably the most likely inhibitor for TMRs or any robotic platform. Another major contribution TMRs could provide to improve firepower and targeting, is ground guidance.[35] Transmitter or laser equipped TMRs could be maneuvered to a target, then emit a beacon or laser designator that an aerial weapon uses to home in on. The transmitter selection would depend upon accuracy and clandestine requirements of the mission. Also, TMRs could be equipped with laser targeting equipment and various optic sensors, which would allow for multiple targeting solutions even during night or cloud covered operations. TMR operators would be able to maneuver the platform from one area to the next in order to identify numerous targets. Also, operators could use the optical sensors to determine ground zero battle damage, thus eliminating the need to re-attack targets which have been destroyed or rendered useless, and at the same time, reattack targets, which are still commission.[36]

Expendable Resources

Another attribute of TMRs is their cost. Even though at this time many are handmade and "one-of-a-kind" vehicles that can run tens of thousands of dollars before sensors are added, they are still less than the $200,000 of an SGLI payment.[37] Once the demand for platforms increases and manufactures can take advantage of assembly-line type processes, costs should plummet. This is also true for several of the sensors such as mini-cameras, IR sensors, GPS, and night vision cameras. Soon the cost for a complete package could be low enough that the platform and sensors could routinely be left behind to self-destruct after an operation as tactical teams egress faster and under less duress.[38]

Scenarios

The following two fictitious scenarios are my examples of how TMRs could be incorporated into a SOF mission. To ensure realism, both were developed with the assistance of SOF tactical team members. Also, the scenarios utilize a few capabilities that either do not exist today or have not been fully tested.

Mission #1

This first scenario outlines a requirement for determining the feasibility of using an abandoned airstrip as a point of debarkation for a SOF tactical team, its equipment. The mission is a covert night operation in a hostile country, and the objective is to capture a terrorist in a nearby town. The UAV and TMR mission requirements are as follows: determine if the runway can support a fully loaded MC-130 landing, provide both aerial and ground images, and identify and warn of any ground movement. The mission begins with an MC-130 loitering in friendly airspace. The tactical team launches three UAVs equipped with optical sensors, long-range communication gear, and carrying variously configured TMRs. The UAVs are flown to the

target area, while the MC-130 remains in friendly airspace. The first UAV enroute to the target area collects terrain and navigation information to later help plan the MC-130 ingress and egress. As it approaches the target area, it relays optical information back to the MC-130, informing the team that the target area is safe for the reconnaissance operation. The UAV is then positioned to provide landing area site selections for the follow-on UAVs and communication links for the TMR operations and to monitor threats. Next, the remaining UAVs land, release their TMRs, and take-off for secondary tasks. The first TMR begins establishing local security by releasing camouflaged sensors that will extend a "perimeter" and monitor any ground movements until the entire mission is complete. The TMRs begin relaying optical information from the ground perspective back to the MC-130. Meanwhile, the second TMR maneuvers to the runway and begins drilling and collecting core samples to determine runway strength. It simultaneously mapps the runway by establishing GPS coordinates, dimensions, and surface characteristics. After the UAVs have downloaded the TMRs, they are used to scout the area. They collect information about the airfield, its buildings, the surrounding area, and road access, thus creating a "layered security blanket over the area. Once sufficient data is gathered, the UAVs return to the loitering MC-130 with (if the mission is scrubbed) or without the TMRs. The TMRs can be left behind to assist in the upcoming night landing. Until then, they can be situated in concealed positions and placed in the sleep mode to conserve battery power with only their self-protection systems on. During the night landing, they could double as navigation aides, laser designators, or provide IR/night vision data back to the approaching aircraft.[39]

Mission #2

The second scenario has tactical teams using TMRs during a hostage situation. Key United States personnel are taken hostage and moved to a large abandoned multi-story building. A team

of TMRs are equipped with devices and sensors to locate exactly where the hostages are held, to map the building's internal hallways and rooms to determine ingress and egress routes, and if necessary, to assist in the actual operation by breaching locked doors, mitigating booby traps, and performing sentry operations. The tactical team operates from an out of sight safe zone and begins the operation by sending in three TMRs operating in unison. The lead TMR is teleoperated to the building. Once the TMR is safely at the building, its path is provided back to the other two TMRs, which now move autonomously to the building. The TMRs make their way into the building where they begin using their sensors in tandem with the lead TMR to ensure full coverage. The lead TMR receives directions from his operator and then forwarding them to the other two TMRs. Each TMR can also be operated independently or take the lead if it becomes necessary. The first is equipped with sensors that allow it to send mapping information back to the tactical team, which will be used later as a blueprint to determine routes. The second TMR is equipped with a radar that has the ability to look through walls to reveal what is on the other side, including humans. The resolution is such that the tactical team is able to decipher which humans are the hostages because of body configurations as some are tied to chairs. Also, the team is able to monitor the terrorists' movements without detection. The TMRs are equipped to plant listening devices so the teams can eavesdrop on the terrorist conversations. Interpreters assist without fear. During the actual assault to recover the hostages, the TMRs could function as force multipliers by performing sentry duty, warning team members via vibrators with directional indicators alerting team members that someone is coming up behind them. TMRs create a diversion and distract the terrorists, using blinding strobe lights and either loud audio shouting out directions to surrender or high pitch tones to disorient the terrorists. TMRs even help disarm the terrorist, moving in close enough to disburse tear gas, capture nets, bolas, and

adhesives they incapacitate the terrorists. Where feasible the TMRs maneuver to the hostages informing them (without the terrorist knowing) via two-way radios what is about to happen, what actions to try and take, and if possible establish a defense line between hostages and terrorists.[40]

These scenarios may not be completely realistic now, but they soon could be based on recent TMR progress and sensor advancements. In real-life, further detailed tactical employment planning must also be worked out. There are numerous other robotic, sensor, and technological capabilities not addressed in either scenario some of which are classified all of which have tremendous potential to improve these scenarios. Many could argue that both scenarios are unrealistic because neither the robotic platforms nor the sensors have been fully field-tested. Just as many would contend the capability already exists, or partially exists, and is at least on the immediate horizon. The objective of these scenarios was to provide some insight and to encourage imaginative thought for future applications.

Notes

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Part 4

Logistical Concerns

Logistical Concerns

If robotic vehicles are to be successful, they will not only have to be technically sound and enhance operation capabilities, but also be highly reliable and easy to maintain without a significant logistics tail or increased manpower. This section will look at the three primary logistical concerns that must be addressed with any weapon system: maintenance, transportation, and supply.

Maintenance Concepts

Maintenance repair concepts are usually broken down into three levels: Organizational, work performed directly on the weapon system while on the flight line or in the field; Intermediate, work performed on items remove from the weapon system, commonly referred to as line replaceable units (LRUs), and taken to a base level shop for repair; Depot, LRUs or components removed from the LRUs which are sent to Depots for more advanced repairs. The entire weapon system could also be sent to the Depot for major overhaul or modifications.

In the Field

The success of a mission could easily rely on how quickly an individual or team can get a malfunctioning robot up and running again.[1] Due to the nature of SOF missions, Organizational

level maintenance will be the primary means for repair and will most often take place in the field. Only in large contingencies or at permanent forward operating locations would Intermediate maintenance capabilities ever be deployed.[2] The success of SOF missions relies heavily on bringing the smallest mobility footprint possible; hence, tactical teams cannot bring test equipment or spare parts, for they must stay light and lean. Therefore, they must have highly reliable systems, which have components that are interchangeable between other systems. This allows them to cannibalize parts from one system to fix another.[3] Due to the differences in size and the various families of robotic systems, the interchange ability requirement may have to be specific to those of like systems. Modular LRUs are imperative for this maintenance concept to be viable.[4]

Design Configuration

Modularity encompasses more than simply having the ability to plug-in components. It is essential that the components not only have plug in capability, but also have no requirement to test or align the components or the system after replacement. This requirement should exist for both new and replacement parts, as well as those parts cannibalized from another system. Just as important, the modularity design must ensure that components are removed and replaced easily, yet have safeguards to prevent improper installation. Ideally, the remove and replace procedures will require simple common-user tools. If possible, the modularity concept should apply to sensors as well. This would enhance maintainability and provide greater flexibility. If the sensors had the same modularity requirements, field tactical teams could reconfigure the robotic platforms to meet the mission, compensate for mission changes, adjust for unforeseen situations, or cannibalize from another platform. This flexibility would allow the tactical teams to make appropriate decisions when a primary sensor is malfunctioning or no longer viable. The

modularity requirement should also be such that it allows members of the tactical team to maintain the system without the need for extensive training, additional personnel and support equipment, or an umbilical cord to the Intermediate maintenance shop or contractor.[5]

Intermediate, Shop Support

The requirement for Intermediate support is a contentious logistics issue. In the late 1980s, the Air Force decided that most weapon systems no longer needed all three levels of maintenance support, and Intermediate repairs for most systems were moved to the Depot. However, the Air Force SOF community was allowed to keep their Intermediate repair capability in order to fulfill their unique mission requirements.[6] For the same reasons, the SOF community should develop and maintain at least some level of robotic Intermediate shop support capability. For Instance, shop support will be required to reconfigure the robotic platforms with the necessary sensors to achieve the various mission requirements. The maintenance skills required to maintain robotic technology parallels the aircraft avionics maintenance skills required to maintain SOF aircraft, particularly in the sensors career field.[7] To enhance the tactical teams' ability to maintain robotic platforms and sensors in the field, it may be prudent to train or at least have them participate in Intermediate support repairs.

Organic vs. Contractor Depot Support

The requirement for Depot level support is without question. However, the question that must be resolved is: "does each of the services develop their own organic capability or pool their resources to develop one organic Depot (that provides repairs for all services), or does SOF and each of the services contract for contractor logistics support (CLS)."[8] Each option has many advantages and disadvantages, with cost and supportability at the center of each. Even though maintaining CLS throughout the life-cycle of a system can be the most expensive, it is likely also

the most advantageous, at least for the early years. Another advantage for CLS is there are numerous contractors. Most contractors contend it would be easier and more cost effective for them to maintain and perform Depot repairs on their own systems. Another option is to limit the Depot, organic or CLS, to overhauls and supply code the LRUs non-repairable and throw them away. A significant cost savings could be realized simply by not funding for Depot level repair support equipment and only procuring equipment needed for overhauls. Regardless which Depot option is chosen, configuration management should be a DOD function, or at least contracted to an independent support contractor.[9] It is imperative that whatever maintenance concepts are used, they must support the field and mission.

Transportation Concepts

To the Theater

Deploying or transporting robotic systems to the field is the next major logistical concern. Obviously those systems such as the M60 tanks outfitted with Israeli tank rollers, mine flail systems, dozers, and M1 Panther vehicles, which have been equipped with teleoperation robotic capabilities, will have the same transportation constraints that unmodified vehicles have today.[10] Moving such large pieces of equipment normally requires sealift, or under special circumstances, strategic airlift like the C-5. This transportation constraint is acceptable to the U.S. Army Corps of Engineers.[11] However, SOF missions frequently do not have the time or luxury to use sealift or even wait for strategic airlift. If ground robotic systems are going to be a viable assets to the SOF community, they must be either man-portable or have a delivery system which requires minimum or no additional burden to the tactical team.[12]

To the Target Area

Robotic systems must be configured to fit within the confines of a MC-130 aircraft and its current SOF loads.[13] Ideally, the robotic vehicles should also be able to be transported in normal suitcase type containers in order to take advantage of moving them via commercial airlines.[14] If the mission allows for the tactical teams to use ATVs, an additional ATV equipped with teleoperation robotics system and a trailer could be added to transport the smaller robotic vehicles needed for mission. The ATV robot could autonomously follow the tactical team via electronic tagging technology. Basically, a member of the team would wear electronic tag, which would emit a signal for the robotic ATV to follow at a safe preset distance.[15] Not only would the robotic ATV function as a pack-mule, but also could become an emergency replacement vehicle or an emergency source of spare parts if one of the other ATVs broke down. If the SOF mission does not allow for ATVs or similar type vehicles due to noise or transportation constraints, then the robotic systems would have to be man-portable, (backpack them in via one of the tactical team members).[16] Robotic systems must also be rugged enough to withstand aerial delivery, since that is one of the primary methods of getting SOF teams to their target.[17] Another method of delivery for TMRs could also be via UAVs. The UAVs could not only be used to deliver TMRs, but also used to pick them up (as discussed earlier) and even provide aerial video for obstacle avoidance, target guidance, and communication links while doing so.[18] In emergency situations, UAVs could also be used to deliver spare parts or additional sensors not originally anticipated for the mission.[19]

Supply Support

One of the more difficult logistics tasks is to adequately predict spare part consumption and ensure availability of required assets. One of the unique challenges for this new weapon system

is to establish and maintain proper stock levels for both the robotic platforms and their sensors, at the same time to keep pace with technology advances.[20] Like maintenance, a key to success will be the modularity requirements. For supply support, modularity will need to incorporate upward and downward compatibility. To keep up with the fast pace of changing technology an upward compatibility requirement will ensure that the latest in sensors, motors, processors, and batteries will work without major modifications. The downward compatibility requirement will help ensure pre-purchased items are not discarded simply because they are no longer the latest technology. Just in time (JIT) arrangements with contractors will also help mitigate excess or outdated supply inventories, while at the same time insuring the right part is available when needed. Sensor technologies, like personal computers and electronic warfare systems, are improving at a pace that it is nearly impossible to keep up in today's competitive markets. Ten years ago we discovered technology had surpassed our new products or systems as we were taking delivery. However, today's technology pace goes one better. Often before acceptance testing has even been completed, newer, superior, and smaller sensor technology is available. The burden of having the right technology available does not rest solely on the logistical supply support system, but begins with the program managers for the individual robotic systems.[21] Program managers not only must find ways to streamline the acquisition process to keep pace with technology improvements, but coordinate closely with their logistic counterparts to guarantee they are aware of any configuration modifications and procure the right items.

Notes

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Part 5

Conclusions and Recommendations

Life is the art of drawing sufficient conclusions from insufficient premises.

—Samuel Butler

Policy

Observations

The most significant finding during this research was a DOD wide lack of written policy or doctrine governing TMRs. In response to congressional direction, the Army established the Unmanned Ground Vehicles/Systems Joint Program Office (UGV JPO) at Redstone Arsenal, Alabama.[1] According to Mr. Walker, UGV JPO, their primary focus at this time is on equipping vehicles such as M60 tank chassis, HUMVs, dozers, M1 chassis, and other existing vehicles large and small with robotic technology. The primary mission for such vehicles is mine clearing operations. He believes that current robotic insertion technology has advanced sufficiently enough that modifying existing vehicles with teleoperation has the least acquisition risk, puts a capability into the hands of the user today, and has the greatest potential to field future robotic technology. These systems are greatly sought after by the Army Corps of Engineers.[2] The SOF community could easily utilize this technology, especially for their ATVs to function in a mule-train type capacity.

It was very obvious that each respective program office is attempting to share technology, to avoid duplication. However, almost every program was unaware of at least one other program office, thus making it nearly impossible for all to share technology. Some program offices are acquiring classified systems, which prevent them from having the ability to openly share technology. Furthermore, some offices are classifying systems that other program offices are fielding in the conventional world.[3] Even though every program office contends they are working openly and freely with the other offices, occasionally there was an atmosphere of self-protection. The atmosphere is very similar to that of the Air Force (AF) and DARPA during the stealth development. "The AF resisted simply because DAPRA had it, and they did not," but this time the resistance includes the Army.[4] There is also some controversy over TMR technology in that one camp believes it has proven TMRs for the most part, while the other believes it is still in the concept/development phase. This leaves the question: "How long until SOF tactical teams have TMRs as a day-to-day asset?" One side contends that the technology is here and it could be less than three years, while the other side protests at best five years, more likely 10 years before TMRs can even be properly tested.

Strategy

Regardless of the timeline to field TMRs, a cohesive acquisition strategy must be developed and executed. Currently most robotic program offices are minimally manned, and often the personnel are also trying to manage other programs simultaneously. I recommend a strategy, which places authority into one program office as a means to gain synergy and oversight among the various program offices. The strategy must address common modular design, frequencies, interoperability, prioritizing sensor and platform development, and batteries. Unlike aircraft and other weapons systems, it would be very difficult to develop a strategy based upon current user

needs, because, the users are either unaware of the technological capabilities or do not have the experience and knowledge to develop requirements. The acquisition strategy should be in accelerated phases and incorporate the users earlier on so they can learn the potential capabilities, establish requirements, and modify the strategy in the immediate future.

Implementation

The key to successful implementation at this time is not providing a fully developed system to the user, but finding a way to educate potential users. The application insight that users bring to developing and fielding any system is priceless. The "hands-on" users also are an excellent source for resolving maintenance and operation issues. Often what is an issue to an engineer is a minor annoyance to the user, and almost the reverse is frequently true. Getting the users involved early on enables program managers and engineers to focus on the pertinent issues, provided the users' influence is tempered with sound acquisition managers.

Conclusions

Robotics, and TMRs in particular, are at a stage similar to aircraft during World War I, but without the urgency of a war to justify incurring significant development or study. Without the war, aircraft technological advancements and military applications would have been much slower, if conducted at all. Without the war what would have driven the requirements? Before the war, and even during the early years of WWI, the airplane was seen as a fad or at best only a reconnaissance platform. Sound familiar? Yet by World War II, the airplane was considered indispensable and some 50 years later, many argue airpower is the only weapon needed, or at least the weapon of choice. It appears that there is little urgency or hard-driving requirements allowing TMR and other robotic technology to progress at other than its own pace at our civilian

institutes. Besides sustaining a reasonable pace, program managers must also avoid chasing after technology. Often users, and sometimes program managers, fall into the same trap; just about the time a system is ready to go, they discover a new technology they must have and end up delaying the program while trying to get it. Trying to keep up with technology changes is a dual-edged sword. On one hand, change is needed to justify staying ahead, conversely, any change costs time and money. The advancements in robotic technology and sensors are currently improving at an almost monthly rate. To strike the right balance requires not only very knowledgeable program managers, but also very knowledgeable users who are actively involved. The key is to get these robots, especially TMRs, in the field as soon as possible and let them develop and advance from there. Thanks to the fast pace of technology improvements, modification is now a way of life. The pace is continually getting faster, and the best way to deal with it is recognize it and prepare to modify. I feel that sometime in the near future robotics will become a viable military option, and in the not to distant future, a military necessity. Who knows, 50 years from now robots may be considered the weapon of choice.

Recommendations

First and foremost I believe there is a need for high-level influence, especially considering John W. Warner's, Chairman of Senate Armed Services, latest order to the Air Force and Army to buy unmanned tanks and planes.[5] Given the chairman's concepts and timeline, an Assistant Secretary of Defense (ASD) for Robotics should be established, adequately manned, and sufficiently funded. The issue is not technology, but how to best use it and finding the money to produce them in quantity, it will require spending money at a "phenomenal rate."[6] This type of monitoring is needed to ensure robotic technology advances at a reasonable pace, receives sound doctrine and policy, interchanges among DOD, all participating government agencies, and

civilian industry, and it obtains the necessary visibility to succeed. This level of leadership reinforces policy guidance such as interoperability, weaponry, and configuration control. Also, this level of oversight helps overcoming cultural barriers and resistance to change.

Second, currently the vast majority of experience and knowledge rests with a very few people; it is imperative that these people stay directly associated with robotic programs until a second generation can be cultivated. Advanced education programs, like the Air Force Institute of Technology (AFIT), need to direct robotic studies, and should establish cooperative research programs with civilian institutes.

Third, an independent evaluation of all robotic programs is warranted to ferret out duplicity and unnecessary secrecy, identify opportunities to pool resources, and provide policy and acquisition recommendations. An independent assessment team diminishes the potential for bias and minimizes the burden of an evaluation on the program offices, all of which appear to be already either undermanned or overworked. The team can also be tasked to recommend organizational structure for the ASD for Robotics office and help establish its priorities.

Fourth, put TMRs in the hands of the intended users as soon as possible. TMRs are not Hawaiian muumuus; one size does not fit all. Trying to create the ultimate TMR, or simply a universal TMR platform for the entire DOD community, or just one service, or even a particular command, or merely for a single SOF unit appears to be unrealistic, expensive, and too restrictive. This type of strategy greatly detracts from the potential flexibility of having families of TMRs from various sources and at the same time shackles the potential for innumerable configurations. The technology growth and momentum are such that, a normal acquisition process would significantly hinder TMR progress.

Fifth, AFSOC should consider adding the requirement for ARGUS to be a TMR or at least have an option package built for TMR installation. The ability to reposition ARGUS after it has been deployed will give the SOF community greater flexibility and enhance the sensors opportunity to fulfill the mission. Plus, they could be retrieved for refurbishment and reuse, salvage, or prevent anyone from discovery their presence.

Paul J. Hoeper, the assistant secretary of the Army in charge of buying weapons contends the military will probably start out using the unmanned weapons the same way we now use the manned ones, until some bright captain figures out the tactics to exploit their potential.[7] Sounds very familiar… the airplane 80 years ago…our next look may be to find out what and where the rest of the countries are headed.

Notes

[1] Phillip B Walker, Unmanned Ground Vehicles/Systems Joint Project Office AMSAM-DSA-UG-M, Redstone Arsenal, Ala., interviewed by author, 10 February 2000.; Matthew J. Kolich, *An Analyze of the Tactical Unmanned Vehicle light During Urban Combat Operations Using the JANUS Combat Model*. Report 99-079 (Monterey, CA.: Naval Postgraduate School, March 1999), 3.

[2] Walker; David G. Kinchel, "Robotics Insertion Technology." *Engineer*, Vol 27 Issue 3, (Aug 1997), 24.

[3] Walker.

[4] George C. Wilson, "A Chairman Pushes Unmanned Warfare" *National Journal*, March 4, 2000, 718.

[5] Ibid.

[6] Ibid.

[7] Ibid.

Appendix A

CL-327

This section is provided CL-327 specifications and additionally pictures.[1]

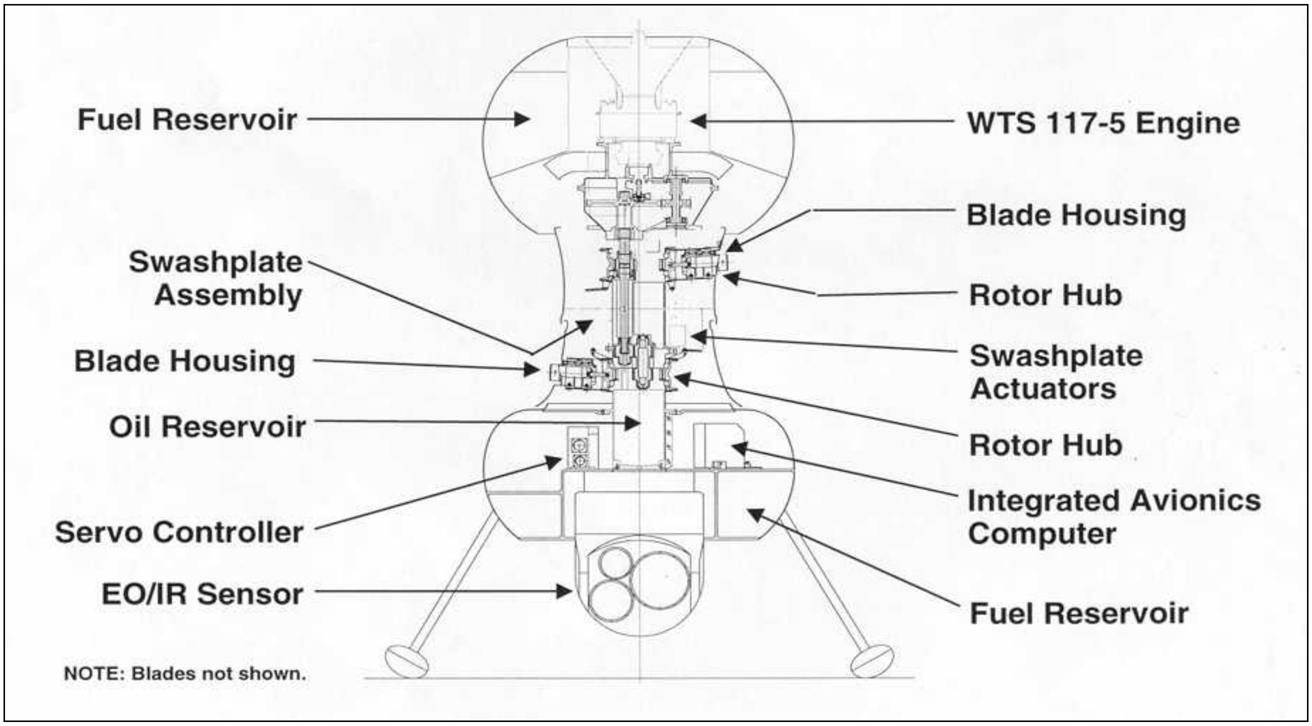
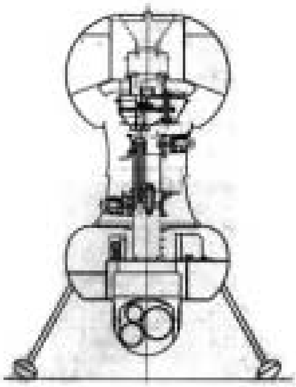


Figure 9. CL-327 Cutway



Endurance:	**6.25 hrs**
Time on Station (50kg sensor):	**4.75 hrs (100 km)** **3.5 hrs (200 km)**
Range:	**100 km (200 km option)**
Rotor Diameter:	**4m (13.1 ft)**
Height:	**1.84m (6 ft)**
Gross T/O Mass:	**350 kg (770 lbs)**
Empty Weight:	**150 kg (330 lbs)**
Payload Capability:	**100 kg (220 lbs)**
Total Fuel (integral)	**180 litres (330 lbs/150 kg)**
Upper Fuel Tank:	**130 litres**
Lower Fuel Tank:	**50 litres**
Speed min/loiter/cruise/dash:	**hover/50/75/85 kts**
Vertical Speed Climb/Descent/Landing:	**7.6/4/1 m/s** **(1500/800/200 ft/m)**

Figure 10. CL-327 Specifications

Figure 11. CL-327

Figure 12. CLS-327 IR Sensor

Figure 13. CL-327 Airborne

Notes

[1] Major Stephen M. Bishop, "Tactical Unmanned Aerial Vehicle (UAV) Reconnaissance." Hurlburt Field Fla. UAV Battle Lab,1999.

Appendix B

LUXOR and TALON

VEHICLE HEAD

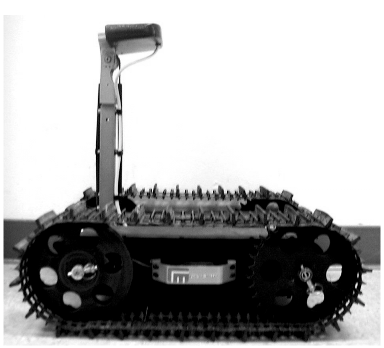
This section provides LUXOR and TALON specifications and additionally pictures.[1]

LUXOR - LIGHT UNEXPLODED ORDNANCE RECONNAISSANCE

CONCEPT:

The LUXOR vehicle is based on Foster-Miller's Lemmings. Developed under a DARPA contract in 1993, Lemmings is a lightweight, submersible wide tack vehicle to operate in urban, field and underwater environments. The Lemming design provides for large variety of payloads and sustained, long range operation. The LUXOR variant is fitted with a controllable arm and optical imaging system.

LUXOR is developed to inspect UXOs from remote locations. LUXOR is controlled by a two-way RF (or via fiber) links as much as 2 miles away. A 14-in arm with pan and tilt can be unfolded from within the track volume that contains the optical imaging system. The LUXOR imaging head is equipped with a CCD camera and four laser diodes. The outer lasers are angled to cross at a specified distance for ranging. The inner lasers have grid-generating optics to aid the user in measuring. The operator can read marking or measure features on the UXO using the grid as a reference off of the base station video monitor. As an option the operator can digitize the image and transmit the image to a command center.



PROTOTYPE SPECIFICATIONS:
Vehicle:
20”l x 15.5”w x 8”w
XX lbs
2-6hr range (depending on batteries)

Camera:

- Dimensions: 0.89 inch diameter, 1.95 inches long, F.O.V. 70 degrees
  - **At 2', FOV= 2.8' x 2.8'**
- 380 Lines of resolution
  - **At 2', 11 lines per inch (about 1/10 inch per line)**

Laser system:

- 2 x 633nm 1mW laser diodes for distance
  - Beams pointed at 4.2 degrees (for intersection at 2 feet)
- 2 x 635mn 5mW laser diodes for size measurement
  - 3-line generating lens on each laser, 2.1 inch spacing at 2'

Monitor:

- Resolution: CRT display with 525 lines *(Resolution is camera limited)*

Options:

- Zoom camera
- Image acquisition and interrogation
- Capture image digitally on a computer and determine exact dimensions (expensive)
- Image printer
- Allows user to print the image viewed by the camera

TALON

Tactically Adaptable Lemming Ordnance Negotiator

Vehicle

- 34"L x 12.5"W x 20"H
- Approx 60 – 70 lbs pending configuration
- 2 – 6 ft/s maximum speed
- 36" arm with gripper claw
- 5.5” camera height
- RF control: up to 1 mile line of sight
- Encoder feedback
- 3-axis compass
- Arm position feedback

Batteries

- 4 Nickel Metal Hydride, or 5590U, or sealed lead acid
- 1-4 hours of operation
- **Charging:**
- Quick-swap
- Optional in-vehicle charging

Cameras

- 4 view multiplexed color CCD
- wide angle, low lux B&W
- 400 TV lines

Operator Control Unit (OCU)

Standard OCU

- Power on/off
- Laser on/off
- Illumination on/off
- Camera tilt up/down
- Arm up/down
- Proportional joystick
- Speed range knob
- Camera selection switch
- 4" active matrix display
- Hi-8 8mm VCR
- Connector for VR goggles
- MIL spec. 5590U battery
- 4 lines by 20 character LCD display for:
- Distance traveled (meters of track displacement)
- Vehicle heading
- Arm position
- **Control Features:**
- Time out (2 sec)
- Range out (2 sec)

Wearable OCU

- Camouflage field vest
- VR goggles
- Handheld controller
- Built in antenna mounts
- 4 hour run time
- Rechargeable batteries
- Adjustable speed control
- 1 mile line of sight operation

Optional Equipment:

- LUXOR (Light Unexploded Ordinance
- Reconnaissance)head
- Zoom Camera
- Laser Pointer
- Night Vision Camera
- Thermal Sight Camera

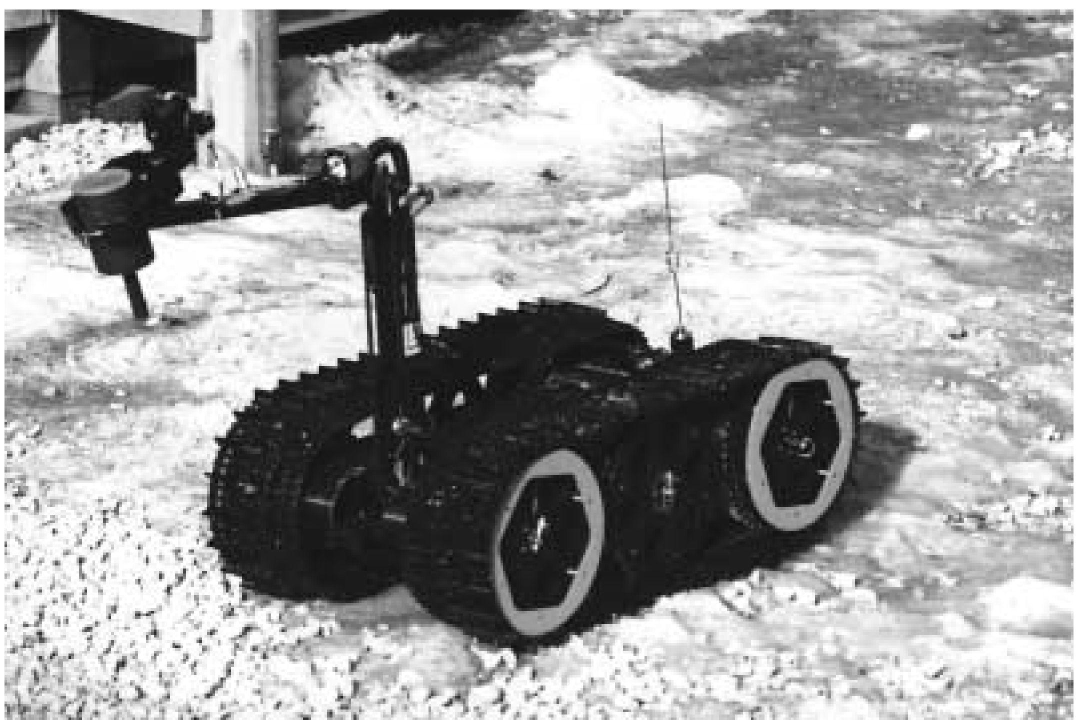


Figure 14. TALON Moving Ordnance

Notes

[1] Arins Mangolds, “Lemmings-Autonomous Surf Zone Survey Platform.” Waltham, Mass.: Foster-Miller, Inc., 1998.

Glossary

AF	Air Force
AFIT	Air Force Institute of Technology
AFSOC	Air Force Special Operations Command
ALUV	Autonomous Legged Underwater Vehicle
ARGUS	Advanced Remote Ground-Based Sensor
ASD	Assistant Secretary of Defense
ATV	All Terrain Vehicle
CLS	Contractor Logistics Support
COTS	Commercial Off the Self
DARPA	Defense Advance Research Projects Association
DOD	Department of Defense
EOD	Explosive Ordnance Detachment
GPS	Global Positioning System
INS	Inertial Navigation System
IPB	Intelligence Preparation of the Battlespace
IR	Infrared
ISRC	Intelligent Systems and Robotic Center
ISR	IS Robotics
JIT	Just In Time
LRU	Line Replaceable Unit
LUXOR	Lightweight Unexploded Ordnance Reconnaissance
MIT	Massachusetts Institute of Technology
NASA	National Aeronautical Space Administration
ORD	Operations Requirement Document
RATLERrm	Robotic All-terrain Lunar Exploration Rover
RCSS	Robotic Combat Support System
RF	Radio Frequency
RMA	Revolution In Military Affairs
SARGE	Surveillance And Reconnaissance Ground Equipment Robot
SOF	Special Operations Force
TALON	Tactically Adaptable Lemming Ordnance Negotiator
TMR	Tactical Mobile Robot
UAV	Unmanned Air Vehicle
UGV JPO	Unmanned Ground Vehicles/Systems Joint Program Office
UGV	Unmanned Ground Vehicle
USAF	United States Air Force
USSCOM	United States Special Operations Command

UUV	Unmanned Underwater Vehicle
UW	Ultra Wide
VTOL	Vertical Takeoff and Landing

computer. An electronic machine that performs high-speed mathematical or logical calculations or that assembles, stores, correlates, or otherwise processes and prints information derived from coded data in accordance with a predetermined program.

laser. Any of several devices that convert incident electromagnetic radiation of mixed frequencies to one or more discrete frequencies of highly amplified and coherent visible radiation.

microwave. Any electromagnetic radiation having a wavelength in the approximate range from one millimeter to one meter, the region between infrared and short-wave radio wavelengths.

muumuu. A full, long loose garment for women, usually in bright print, on size fits all.

radar. A method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of very high frequency radio waves reflected from their surfaces.

robot. Any man like mechanical being, as those in Karel Capek's play R.U.R. (Rossum's Universal Robots), built to do routine manual work for human beings. b) any mechanical device operated automatically, especially by remote control, to perform in a seemingly human way.

robotics. The study of robots, their design, manufacture, use etc.

turn turtle. To turn upside down; capsize.

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